

## Aerodynamic Shape Optimization of the X-37 Configuration for Improved Stability and Performance

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The objective of this work was to apply numerical shape optimizations to the X-37 in order to improve its longitudinal stability and performance during descent. Wind tunnel test results for this vehicle, which were designed by Boeing at Seal Beach, California, showed longitudinal instability at Mach numbers between 0.6 and 1.5 and at moderate to high angles of attack. The instability was attributed to flow separation from the wing and tails. As part of the X-37 development program, Ames was requested to assist in refining this configuration through the use of numerical-optimization techniques developed under the High Speed Research Program.

The X-37 configuration is shown in the figure. It has an all-moving canted tail and a low-mounted wing, which is coincident with the lower surface of the fuselage. Optimization efforts were limited to supersonic conditions for the configuration with an aft extension to smoothly close the fuselage since the subsonic solution accuracy was questionable with the large blunt base. The design goals were to improve the longitudinal stability by increasing the lift coefficient for which the pitching-moment curve

slope was greater than 0.025 for Mach numbers between 0.8 and 1.5, and to improve the subsonic/transonic aerodynamic performance. The geometric constraints provided by Boeing included a fixed airfoil thickness along the wing flap hinge line, wing and ruddervator minimum thickness, and a leading-edge bluntness constraint. Wing twist and dihedral angle constraints were also provided along with ruddervator-sweep and dihedral-angle constraints.

The optimization tools employed in this design activity are embodied in the Ames Aerodynamic Shape Optimization (ASO) Library. The tools consisted of flow solvers, grid-generation and perturbation tools, design-variable and geometric constraint implementation tools, gradient computation methods, and numerical optimization methods. Some of the tools were commercially available, others were developed in-house; still others were modifications of commercial software. The basic optimization tool is the commercially available SYN107 multiblock code which consists of both a Euler flow solver and an adjoint solver, coupled to a constrained-optimization algorithm. The use of an adjoint solver provides efficient gradient information at a computational cost that is nearly independent of the number of design variables and of the convergence level of the flow solver. Geometric improvements to the wing and fuselage are obtained by optimizing the coefficients of analytic shape functions added to the surfaces.

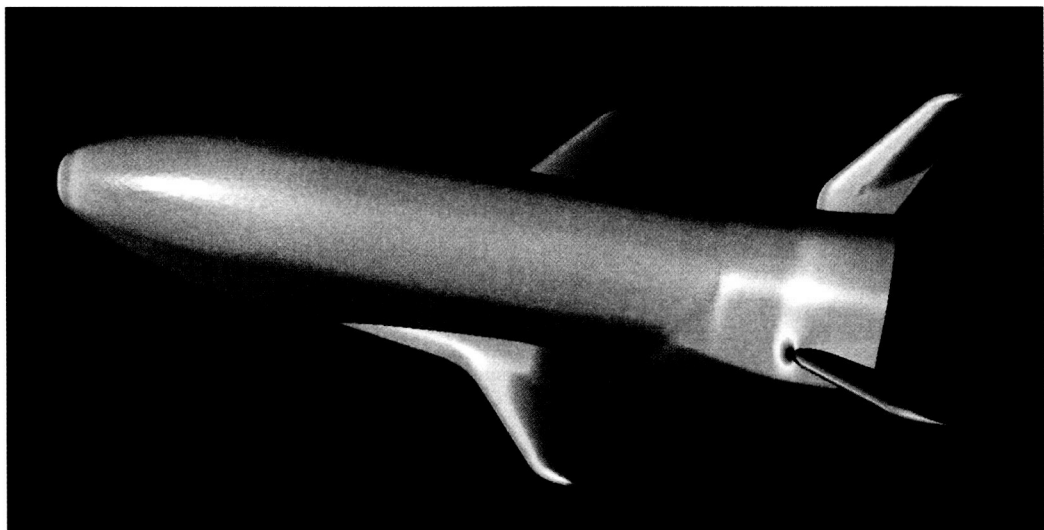


Fig. 1. AIRPLANE computation of the X-37 configuration, colored pressure coefficient contours at Mach = 1.2, angle of attack = 10 degrees.

High-fidelity analyses were obtained through the use of the AIRPLANE code, an unstructured tetrahedral Euler method. The unstructured grid method handles arbitrary geometries without incurring large increases in time or difficulty for increased geometric complexity.

Euler-based numerical optimization and hand design methods were used to modify the wing, body, and ruddervator of the configuration to improve stability and performance. Several parametric studies of the wing and ruddervator such as the wing fore and aft positions, ruddervator dihedral angle, span, vertical position, sweep and twist modifications were also performed. Several different objective functions were used to address the stability problem, both single-point design with a target pitching moment, and composite multipoint objectives to directly modify the slope of the pitching-moment curve between two angles of attack. However, minimizing a weighted drag/lift objective function at a fixed Mach number of 1.2 and an angle of attack of 10 degrees was the most effective objective for both stability and performance. This lent credibility to the presumption that reducing the pressure drag reduces or delays the shock-induced flow separation, thereby improving performance and stability.

AIRPLANE analyses of the optimized design predicted improved stability over the Mach number range of 0.8 to 4.75. All geometric constraints were satisfied, including the additional constraint of no lower-surface leading-edge droop. In addition, significant performance improvements were achieved for the redesigned configuration at Mach numbers of 0.8, 1.2, 1.5, 1.8, 3.0, and 4.75. An 8% total drag reduction representing approximately 330 counts was obtained at the design Mach number of 1.2. In addition, a 10% reduction in drag was obtained at the secondary design Mach number of 0.8.

Many of the parametric modifications to the ruddervator (dihedral angle, span, vertical position, twist, and sweep angle) and wing (fore and aft position) made significant improvements to the longitudinal stability, but they were not included in the final design because the changes could adversely affect other mission requirements.

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